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## THE GREENHOUSE EFFECT OF VOLCANIC DUST

By W. J. HUMPHREYS

A dense, dry fog, persistent and all-prevailing, made the European summer of 1783 forever memorable in meteorological literature and tradition. Among the most interesting of the numerous recorded comments about it are those of Franklin who, in May 1784, wrote as follows:

> During several of the summer months of the year 1783, when the effects of the sun's rays to heat the earth in these northern regions should have been the greatest, there existed a constant fog over all Europe, and great part of North America. This fog was of a permanent nature; it was dry, and the rays of the sun seemed to have little effect toward dissipating it, as they easily do a moist fog arising from the water. They were indeed rendered so faint in passing through it that, when collected in the focus of a burning-glass, they would scarce kindle brown paper. Of course, their summer effect in heating the earth was exceedingly diminished.
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> Hence the surface was early frozen.
>
> Hence the first snows remained on it unmelted, and received continual additions.
>
> Hence perhaps the winter of 1783–4 was more severe than any that happened for many years.
>
> The cause of this universal fog is not yet ascertained. Whether it was adventitious to this earth, and merely a smoke proceeding from the consumption by fire of some of those great burning balls or globes which we happen to meet within our course round the sun, and which are sometimes seen to kindle and be destroyed in passing our atmosphere, and whose smoke might be attracted and retained by our earth; or whether it was the vast quantity of smoke, long continuing to issue during the summer from Hecla, in Iceland, and that other volcano which arose out of the sea near that island, which smoke might be spread by various winds over the northern part of the world, is yet uncertain.
>
> It seems, however, worthy the inquiry, whether other hard winters, recorded in history, were preceded by similar permanent and widely-extended summer fogs. Because, if found to be so, men might from such fogs conjecture the probability of a suceeding hard winter, and of the damage to be expected by the breaking up of frozen rivers in the spring; and take such measures as are possible and practicable to secure themselves and effects from the mischiefs that attend the last.[1]

From these remarks it appears that Franklin suspected that this dry fog might be volcanic dust from Iceland. This supposition seems to be fully confirmed by the fact that Skaptar Jökull exploded violently on June 8 of that year, and again on June 18.

Franklin seems further to infer, and naturally because of the enfeebled insolation, that in Europe, where dry fog prevailed, the summer of 1783 was abnormally cool. On the contrary, however, as pointed out by E. L. Hawke,[2] this summer was very abnormally warm in western and northern Europe. And the reason therefor, or at least what appears to be a sufficient reason, is the greenhouse effect of relatively coarse volcanic dust (probably flaky rock fragments, broader than thick and floating flatwise). Such material is a much better absorber of the long-wavelength earth radiation than it is of the much shorter wavelength solar radiation,[3] and therefore, so far as absorption alone is concerned, must produce a direct greenhouse effect. Turning now to symbols for simplicity and brevity, let $I$ be the 24-hour average intensity (energy flow per square centimeter per minute) of the normal component of the incoming sunshine, and $a$ the fraction of this component absorbed by the dust; and let $E$ be the 24-hour average intensity of the vertical component of the radiation, chiefly terrestrial, but a little reflected solar, just beneath the dust, and $b$ the fraction of this mixed component absorbed by the dust. Clearly, of each of the two quantities of energy, $aI$ and $bE$, absorbed by the dust one-half goes outward and one-half inward, partly, in each case through direct reradiation by the dust and partly through radiation by the air warmed by the heated dust.

Obviously, when equilibrium is reached the amount of the inner radiation, $E$, that directly and indirectly gets *out* through the dust layer is exactly equal to the amount of the outer radiation, $I$, that gets *in* through this layer, otherwise the earth would be growing progressively colder or steadily warmer over and above the normal seasonal changes. Therefore

$$E-\frac{b}{2}E=I-\frac{a}{2}I$$

or

$$E=I\frac{2-a}{2-b}$$

When there is no dust, or when $a$ and $b$ each is zero, or equal to each other whatever their value,

$$E=I.$$

But when dust is present and of the kind for which $b$ is greater than $a$, $E$ is greater than $I$, and the surface temperature is increased.

Let, for example, the absolute temperature of the radiating virtual under surface be 300° A. when there is no dust, then in the presence of a dust layer covering 10 percent of the sky everywhere, and for which $a=\frac{1}{5}$, and $b=\frac{4}{5}$, the absolute temperature, $T$, of this under surface may be computed as follows, assuming that the intensity of the radiation varies directly as the fourth power of the absolute temperature of the radiating surface, which it does, roughly, for most substances:

$$T^4=300^4\left(\frac{9}{10}+\frac{1}{10}\,\frac{2-\frac{1}{5}}{2-\frac{4}{5}}\right)=(303.68)^4$$

and

$$T=303.68°\text{A},$$

an increase of 3.68° C. owing to the dust. If but 5 percent of the sky were covered the increase of temperature would be 1.86° C. If the sky were completely covered by this dust—no interstices through which radiation might dodge the dust—the temperature increase would be 32° C.

[1] Sparks, "Life of Benjamin Franklin", 6: 455–457.
[2] Q. Jr. Ry. Meteorol. Socy., 63, 456, 1937.
[3] Coblentz, Publications of Carnegie Institution of Washington, Nos. 65 and 67.

If, again, $a=\frac{1}{4}$ and $b=\frac{3}{4}$, with the other conditions as above, the several temperature increases would be 2.95° C., 1.49° C., and 26.32° C., respectively.

Apparently, therefore, it is logical enough to attribute the abnormally high temperatures of western and northern Europe of June–August 1783 to the direct greenhouse effect of the relatively coarse volcanic dust from Icelandic volcanoes, Skaptar Jökull especially.

Franklin further states, in the quotation above, not as a surmise, but as an observed fact, that the winter of 1783–84 was abnormally cold. So it was, and so were the 3 years 1784–86 inclusive.[4] However, this widespread low temperature, covering North America, Europe, and northern Asia, or all places where instrumental observations were taken, and presumably, therefore, world-wide, hardly could have been caused by the dust from Skaptar Jökull, or, at any rate, not by its coarser portions, but most likely chiefly, if not well-nigh wholly, by the much higher and far finer dust from Asama in Japan, which exploded violently on August 2, 1783, and more violently still on August 5, 1783. Dust of this sort and size that in appreciable amounts may remain in the stratosphere even 2, 3, or, possibly, 4 years, depletes passing radiation essentially by diffraction, or scattering, and not mainly by absorption, as do relatively large particles. The theory of this inverse greenhouse effect of fine volcanic dust [5] will not be repeated here as it is rather long and tedious. It shows that the fine dust in question shuts out solar radiation far more effectively than it shuts in earth radiation and therefore causes a greater or less decrease of surface temperatures.

Presumably, then, the summer of 1783 was rendered abnormally warm in western and northern Europe by the then prevailing pall in that region of relatively coarse volcanic dust from Skaptar Jökull, especially; and the following 3 years abnormally cold over much, if not all, of the world by the high, fine dust from Asama.

And it comes to this: Volcanoes, like the man in the fable, can blow hot and blow cold with the same breath, but that shall not provoke us to wrath.

[4] W. Köppen, Zeit, Ost. Gesel. für Meteorol. 8, 260, 1873.

[5] Physics of the Air, McGraw-Hill Book Co., 1929.

# SHIELDED STORAGE PRECIPITATION GAGES [1]

By J. Cecil Alter

[Weather Bureau, Salt Lake City, Utah, June 1937]

The gist of nearly two centuries of precipitation gage literature is, that a precipitation gage in any location freely exposed to the upper arch of the sky, will collect a perfect sample of either rain or snow when the air is calm or is moving with only light to moderate velocity, such as are the conditions when much, if not most, of the precipitation occurs.

In the path of a strong wind, however, the precipitation gage, like any other isolated object or structure, becomes a disturbing obstacle, around which, and over the top of which, the immediately adjacent air passes with increased speed. Thus in strong winds the fabric of falling snow is expanded over the gage where the wind runs fastest and the snow pattern is condensed in a spot immediately to the lee of the gage where the wind slows up. As a result, a deficiency of snow is deposited over the gage, and an equal excess is deposited in a similar area a few feet to the leeward. That is to say: During strong winds a small but variable part of the snow rightfully belonging to the gage misses the gage.

The distortion of the sample thus taken, or the deficit in the catch, increases with increased wind velocity; and is from two to four times greater for snow than for rain. The well-known decrease in the catch with increase in elevation of the precipitation gage above ground, results chiefly, it is usually conceded, from the increase in wind velocity in the loftier positions.

For the usual ground exposures where probably 95 percent of the Weather Bureau gages are exposed, the shrubbery, fences, orchards, shade trees, buildings, and other objects rising on the horizon of the precipitation gage tend to slow up and equalize the speed of the wind over the gage (decrease the range between minimum and maximum velocity). This consequently increases the catch of moisture, and substantially decreases the variability of the catch.

Skyscraper roof exposures so often deprecated as precipitation gage sites are not all bad, for the building itself is often ideally fitted with an overhanging ornamental cornice which substantially prevents the wind stream from rising and racing at increased speed across the roof. On such a shielded roof a precipitation gage may be placed fairly near the edge, or in any areaway available with reasonable safety to the catch, for the building itself constitutes a huge, shielded precipitation gage.

The user of precipitation data may rest assured, however, that these general defects may nearly all be considered of a minor order or character; because the data, after all, bear a pretty constant ratio to the general precipitation over an area of a few hundred square miles nearest the gage. Thus most precipitation data, despite their well-known defects, are a factor of comparatively dependable constancy among such related variables as evaporation, transpiration, surface run-off, and soil absorption, in hydrologic formulas.

No considerable number of Weather Bureau gages in use are exposed to the full sweep of the wind from any direction, since they are nearly always placed in convenient but sequestered positions on farmsteads or home premises where a certain amount of needful sheltering is always present. Nevertheless, there are usually a few gages in important sections of every State which have inadequate windbreaks, at least in certain quadrants of the gage horizon, and therefore leave the precipitation gage unduly exposed to the certain winds.

Probably a still larger number of gage exposures could be improved if some simple, uniform system of shielding were available, to reduce the variability of the catch in the differing exposures of neighboring gages, and for different velocities and directions of wind over the same gage; that is, if a trustworthy, artificial windbreak could be attached to the gage to give all exposures a semblance of uniform wind eddy control.

A new need for dependable snow gages exists in the unpopulated mountain areas of the West, where there is no one to make daily observations. In these cases the gage must not only effect a reliable collection of perfect samples or falls of snow and rain, in calms as well as in strong winds, but it must preserve this moisture until the gage can be visited and the contents measured (say at the end of the month, since all Weather Bureau data are published in monthly units). Wherever there is a need for a snow survey course, there is a need for at least one sea-

[1] Delivered before the American Meteorological Society at Denver, Colo., June 22, 1937.